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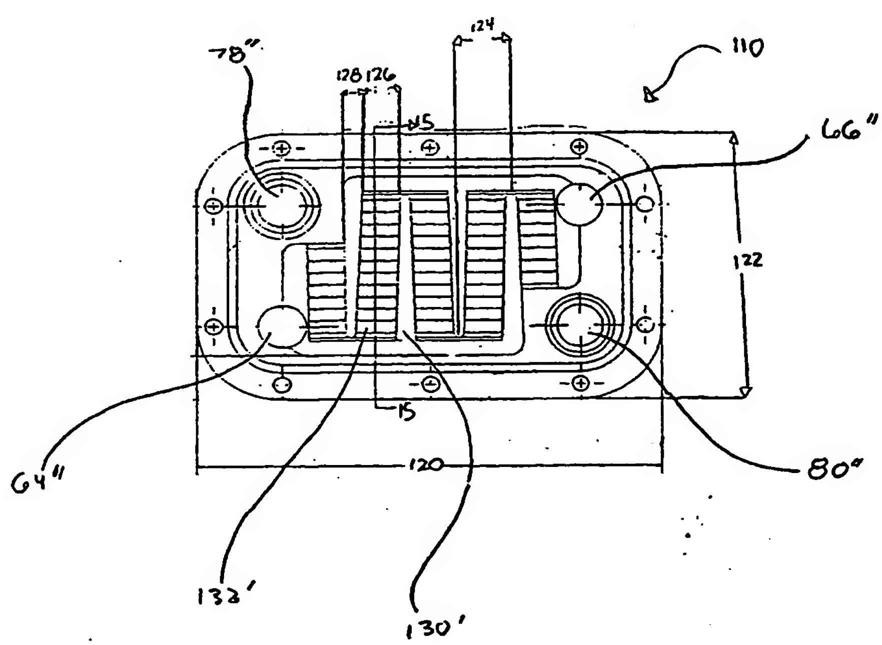

(57) Abstract

A plate for a commercial size plate style heat exchanger utilizes micro-channels in the flow paths of the working media thereby greatly increasing the surface area to volume ratio and inducing laminar flow in the working media. This provides greater heat transfer capabilities and reduced pressure losses, resulting in an increased overall heat exchanger efficiency. The structure of the micro-channel plate heat exchanger is based on stacked micro-channel plates that have been rotated 90° with respect to each other.

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MICRO-CHANNEL HEAT EXCHANGER

This invention relates to an apparatus for accomplishing heat transfer between two media. More specifically, the invention is a plate heat exchanger wherein efficient heat transfer between liquids, gasses or two-phase flow is accomplished by utilizing a series of micro-channels through which said media flow while transferring heat.

Background of the Invention

Conventional heat exchangers are available in numerous configurations, the most common configurations being, tube and shell, baffle, fin or plate. However, the prior art heat exchangers regardless of the design configuration, have several drawbacks. Conventional heat exchangers with large heat capacity requirements are physically cumbersome, which can be problematic when transporting, installing and maintaining such units. The prior art heat exchangers are typically fabricated within a restricted range of heat removal capacities for a given size and design to allow in-stock availability. Conventional heat exchangers are typically large, and if system conditions change, modification of the existing heat exchanger is impossible and full replacement is necessary. Another difficulty with the current industry commercial heat exchangers is that under certain conditions, the heat exchanger surfaces tend to become fouled and may need frequent cleaning. Additionally, inherent inefficiencies exist that have necessitated heightened pumping or energy requirements.

Micro-channel heat exchanger technology has been developed for small applications, having laminar flow within small channels. With conventional heat exchangers, turbulent fluid flow efficiently transfers

heat by convective means within tubes or between plates. As turbulent fluid flow passes within tubes or between plates, a laminar boundary layer forms adjacent to the solid matrix. This fluid boundary layer greatly inhibits heat transfer. In conventional heat exchangers, as fluid velocities are reduced, the laminar boundary layer increases. In heat exchangers that utilize micro-channels, since all the developed flow is laminar boundary layer, reducing the fluid velocity can not increase the boundary layer. Thus, decreasing the fluid velocity in heat exchangers utilizing micro-channels, has very little effect on the overall heat transfer capability of the heat exchanger compared to conventional heat exchangers that have turbulent flow within larger flow channels or tubes.

One drawback of utilizing micro-channels in heat exchangers is that the fluid pressure drops due to frictional losses within micro-channels can be high. Thus, to keep pressure losses reasonable, micro-channel lengths must be kept short. This has not been a problem for small scale applications such as with computers as the micro-channel lengths are inherently short. To be able to use superior micro-channel technology for larger applications requires that fluids be efficiently delivered to numerous parallel short micro-channels to keep friction at a minimum.

Summary of the Invention

The present invention provides a plate having a top side and a bottom side for use in a heat exchanger device wherein the plate comprises a metal or polymer material having a plurality of micro-channels on the top side, wherein each micro-channels is characterized as having a height of from about 2 to about 12 mm, a channel width of from about 0.1 to about 1.0 mm, a

separation wall between micro-channels of from about 0.1 to about 1.0 mm and a channel length of from about 1 cm to about 5 cm. Preferably, the micro-channel height is from 2 to 6 mm, width and separation wall from 0.2 to 0.6 mm and length of from 1.5 to 3.0 cm. Preferably, each plate is predominantly circular or quadrilateral in shape and having an inlet opening and an outlet opening each communicating with opposite ends of a series of micro-channels. Preferably, the plate is made by milling or machining or injection molding process using aluminum as a metal or a polymer composite material having graphite or metal fibers embedded therein.

The present invention further provides a heat exchanger, comprising a plurality of inventive plates stacked together, wherein the heat exchanger further comprises an inlet, a plurality of plates are alternately stacked to form a plate heat exchanger wherein there is a first fluid and a second fluid between which heat is transferred. This stacked plate configuration defines separate channels between adjacent stacked plates so as to create a flow path on the top side of each plate for one of said fluids to flow. Since the fluids are not in communication, the first fluid and second fluid flow across the top sides of alternate plates. The plates have a plurality of micro-channel passages to allow adequate fluid capacities to flow through micro-channels and reduce boundary layer effects, to keep micro-channels short and to greatly increase the surface area to volume ratio with respect to conventional commercial heat exchangers. When the first fluid and the second fluid are flowing through their flow paths on the top side of alternately adjacent plates, they are in close enough

contact to enable high efficiency heat transfer via conduction through the media.

The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, both the organization and method of operation, together with further advantages and objects thereof, may best be understood by reference to the following description taken in connection with accompanying drawings wherein like reference characters refer to like elements.

Brief Description of the Drawings

FIG. 1 is a cross sectional view of an exemplary micro-channel;

FIG. 2 is a perspective top face view of a micro-channel plate;

FIG. 3 is a perspective top face view of a second plate;

FIG. 4 is a perspective top face view of an open channel second plate;

FIG. 5 is a sectional top face view of one half of a micro-channel plate stacked above an open channel second plate;

FIG. 6 is a perspective view of an assembled micro-channel plate heat exchanger;

FIG. 7 is an exploded view of the micro-channel plate stacking arrangement;

FIG. 8 is a cross sectional view taken along line 8—8 in FIG. 2;

FIG. 9 is a cross sectional view taken along line 9—9 in FIG. 3;

FIG. 10 is a cross sectional view taken along line 10—10 in FIG. 4;

FIG. 11 is a perspective top face view of an alternative embodiment first micro-channel plate;

FIG. 12 is a perspective top face view of an alternative embodiment second micro-channel plate for use in conjunction with the plate embodiment of FIG. 11.

FIG. 13 is a perspective top face view of another alternative embodiment rectangular micro-channel plate;

FIG. 14 is a cross sectional view taken along line 14—14 in FIG. 13;

FIG. 15 is a perspective top face view of the preferred alternative embodiment rectangular micro-channel plate;

FIG. 16 is a cross sectional view taken along line 15—15 in FIG. 15; and

FIG. 17 is a magnified view of a portion of the plate of FIG. 14.

Detailed Description

A preferred embodiment of the present invention comprises two end plates located at the distal ends of a plate stack formed from alternately stacked first medium and second medium plates. The plates and end plates have a plurality of holes defined around the plate or end plate perimeter that align upon stacking to allow a suitable fastener to pass through the holes so as to facilitate assembly. Each end plate has an opening to accommodate the flow of the first medium and an opening for the flow of the second medium. Some plates have micro-channels on their top faces that allow flow of a medium through the respective medium plate. Commingling between the two heat transfer media, is prevented by O-rings (or in embodiments that cannot be disassembled, this is done by direct mechanical sealing), such that the two media remain in close proximity thereby enabling efficient heat transfer.

Referring now to FIG. 1, which is a cross sectional view of a micro-channel, a typical micro-channel height 54 is 3.0 mm, typical micro-channel width 56 is 0.25 mm, typical micro-channel repeat spacing 52 is 0.75 mm, and typical micro-channel length is 15 mm. These dimensions will vary with system operating parameters including pressure, flow and temperature, as well as the chemical composition of the heat transfer media. Alternate micro-channel dimensions are suitably employed for optimal efficiency under varying conditions. Exemplary ranges of the micro-channel dimensions include a height within the range of approximately 2 mm to 12 mm (0.1 to 0.5 inch), a micro-channel width within the range of approximately 1 mm to 1 mm (0.005 to 0.05 inch), an adjacent micro-channel separation within the range of approximately 0.1 mm to 1 mm (0.005 to 0.05 inch) and a micro-channel length within the range of approximately 6 mm to 5 cm (0.25 to 2 inch).

Referring to FIG. 2, the top face of a micro-channel heat exchanger plate 32 is illustrated. Note that in the preferred circular plate embodiment, the first medium and second medium plates may be identically constructed and are distinguishable only by the medium that flows across the plate faces, or by the orientation of the plates. The first medium and second medium plates have four substantially similar apertures 12, 13, 14 and 16 evenly spaced near the plate's perimeter. Apertures directly opposing each other accommodate the same medium. Medium apertures 12 and 16 act as inlets and outlets for medium flow across plate 32, directing medium flow into medium path 28. Micro-channel end plates 30 act to seal off the flow of medium through medium path 28 between medium apertures 12 and 16 thereby forcing the medium to flow through micro-channels 25. The dimensions of the

micro-channels induce laminar flow and optimize the surface area to volume ratio.

Support teeth 26 are positioned in the medium flow path side of medium apertures 12 and 16 to provide support to adjacent plate 32. In alternate embodiments support teeth 26 may be eliminated.

The other pair of directly opposing apertures, which are pass through apertures 13 and 14, provide a medium flow path for the other medium allowing it to bypass plate 32, flowing into the medium apertures and through the medium flow path 28′ of an adjacent micro-channel plate 32′.

In heat exchangers employing micro-channel heat exchanger plates that are designed to be disassembled, pass through apertures 13 and 14 have O-ring groove 24 around the aperture circumference to receive an O-ring for sealing against unwanted medium commingling between the two heat transfer media. Located around the outer periphery of plate 32 is plate O-ring groove 20. When plates are stacked together, O-rings are inserted in pass through aperture O-ring groove 24 and plate O-ring groove 20 thereby forming a seal between the top face of plate 32 and the bottom face of the adjacent plate. The plate O-ring seals against medium leakage from medium flow path 28 created between two adjacent plates. The pass through aperture O-rings seal the medium flow path through apertures 13 and 14 that bypass plate 32 thereby preventing medium communication between the two heat transfer media. The O-rings employed will be selected from suitable commercially available standard O-rings. While in the preferred embodiment, the stack of micro-channel plates can be disassembled, other embodiments as discussed hereinbelow employ plates that are fixed together in manners not designed for disassembly.

Micro-channel plate 32 has a plurality of equally spaced assembly holes 18 about a circle on the outer periphery of the plate that align coincident with the aligning of apertures 12, 13, 14 and 16 of adjacent plates. This facilitates assembly by the engagement of a suitable fastening means, for example industry standard fasteners such as threaded rods, washers and nuts.

Referring to FIG. 3 and FIG. 4, perspective views of other embodiments of a second plate, different medium flow paths 29 and 31 can be incorporated onto plates 34 and 36 to accommodate media that do not need micro-channel construction for efficient heat transfer. In such embodiments, micro channels are not employed, but rather single open channel medium flow path 29 or 31 is used. Variations in the design of the medium flow paths may be governed by the characteristics of the type of medium used or the heat transfer efficiency desired.

FIG. 5 is a partial cut away view of a stacked plate arrangement between alternate plate 34 (as shown in FIG. 3) and micro-channel plate 32 (as shown in FIG. 2). In the illustration, one of the two plates is rotated 90° relative to the other plate, whereby apertures 16 and 12 of the top plate align with apertures 14′ and 13′ of the lower plate, and apertures 13 and 14 of the upper plate align with apertures 16′ and 12′ of the lower plate. The flow of the two heat transfer media in this particular arrangement are perpendicular to each other. The first medium in micro-channel plate 32 flows from medium inlet aperture 12 through micro-channels 25 to medium outlet aperture 16. The second medium in channel plate 34 flows from medium inlet aperture 12′ to medium outlet aperture 16′. FIG. 5 illustrates that plates have been oriented

90° from layer to layer, such that the second medium flowing across plate 34 through apertures 12′ and 16′ of plate 34 also bypasses micro-channel plate 32 via pass through apertures 13 and 14 of micro-channel plate 32. In this fashion, the two media can simultaneously flow through numerous stacked pairs of alternating plates without commingling.

Referring to FIG. 6, an assembled heat exchanger comprising plural plates, and to FIG. 7, an exploded view showing three plates in stacked arrangement, it can be seen that end plates 38 have a second medium inlet opening 42 and an outlet opening 44 that align with a given pass through inlet or outlet apertures 13 or 14. The end plates also contain first medium inlet 46 and outlet 48 that align with medium inlet or outlet aperture 12 and 16 of micro-channel plate 32. End plates 38 are substantially similar and situated parallel, but are oriented 180° apart. Optional shell 50 surrounds stack 51 of plates and is held in place by end plate groove 53 which is defined in the end plate. The heat exchanger is held together by a suitable fastening means, such as threaded rod, washer, and nut combination 40 which is inserted through assembly holes 18 in end plate 38 and stacked micro-channel plates 32.

First medium plates and second medium plates are alternately stacked to form a heat exchanger. This configuration defines a channel between adjacent plates so as to create medium flow path 28 on the top face of each micro-channel plate 32 from inlet aperture 12 to outlet aperture 16. Each plate is suitably oriented 90° with respect to adjacent plates.

Referring to FIG. 7, a perspective view of the plate stacking arrangement showing micro-channel plates 32 oriented 90° with respect to adjacent plates, it can be seen that the stacking arrangement results in four

cylindrical columns for medium that extend the length of the heat exchanger and perpendicular to the faces of the plate stack. Directly opposing columns (those 180° apart), fill with the same heat transfer medium. One of the directly opposing columns acts as the inlet flow for that medium and the other column acts as the outlet flow.

In operation, the first medium flows from end plate 38 first medium inlet opening 46, filling its inlet column and flowing simultaneously through medium aperture inlet 12, flow channel 28, micro-channels 25, and medium aperture outlet 16 of each alternate plate in the stacked arrangement, exiting into the outlet column and flowing out the first medium's outlet opening 48 in the other end plate 38. The first medium is prevented from flowing into adjacent plates by the O-ring seal formed around the pass through apertures 13 and 14 and the perimeter O-ring seal. In embodiments of heat exchangers according to the invention that do not disassemble, the first medium is prevented from flowing into adjacent plates by direct mechanical sealing as accomplished by brazing or adhesives.

The second medium undergoes a substantially similar flow route except that its flow is in a counter current direction to that of the first medium in the illustrated embodiment. The second medium enters end plate 38 second medium inlet opening 42 at the opposite end of the heat exchanger from where the first medium entered, and flows simultaneously through alternating adjacent micro-channel plates from which the first medium is flowing in, and exits out end plate 38 second medium outlet opening 44. Therefore, the first and second heat transfer media flow in a counter current direction perpendicular to each other through alternating micro-channel plates, wherein heat is

transferred between the two media through the plates. When the first medium and the second medium are flowing through their respective plates, they are in close enough contact to enable high efficiency heat transfer.

Referring to FIG. 8, which is a cross sectional view of micro-channel plate 32 taken through line 8—8 of FIG. 2, micro O-ring channels 25, pass through apertures 13 and 14, plate O-ring groove 20, medium aperture O-ring 24 and perimeter holes 18 can be seen in relation to micro—channel plate 32.

Referring to FIG. 9, which is a cross sectional view of plate 34 taken through line 9—9 of FIG. 3, the flow path 29, medium apertures 12′ and 16′, plate O-ring groove 20′, and perimeter holes 18 can be seen in relation to alternate embodiment second plate 34.

Referring to FIG. 10, which is a cross sectional view of plate 36 taken through line 10—10 of FIG. 4, flow path 31, medium apertures 12′′ and 16′′, plate O-ring groove 20′′, and perimeter holes 18 can be seen in relation to another embodiment of second plate 36.

Referring now to FIG. 11 and FIG. 12, which comprise first and second plates in accordance with an alternative embodiment, it can be seen that first and second plates 60 and 62 are generally square and suitably comprise mirror images of each other. Plate 60 includes inlet port 64 and outlet port 66. (Note that either of these two ports can be the inlet or the outlet, depending on the direction of flow through the plate). The plates are suitably relatively thin (5.0 mm in a particular embodiment) and ports 64 and 66 define openings that pass from one side of the plate to the other side thereof. On the illustrated side of the plate, openings 64 and 66 communicate with flow channel area 68 and 70 respectively, which are adapted to communicate medium to or from ports 64 and 66 to or

from relatively long finger like channels 72 and 74 respectively. Channels 72 and 74 have micro-channel structures 76 positioned therealong, wherein a given micro-channel 76 is positioned between corresponding channel 72 and channel 74.

The back side of the plate relative the side viewable in FIG. 11 is suitably flat or otherwise smooth, as it will define a top or seal that rests on top of the next plate adjacent thereto and it may also define the end of a stack of plates.

In the operation of a heat exchanger employing a plate according to this embodiment, a medium flow path is provided from port 64, through area 68, down finger-like channels 72, through micro-channel structures 76, and out finger-like channels 74, through area 70, and ultimately out port 66. Of course, if the flow direction is reversed, the flow path proceeds from port 66, through area 70, down channels 74, through micro-channel structures 76, out finger-like channels 72, through area 68 and out of port 64.

In a corresponding manner to that employed with the plate embodiments described in connection with FIGS. 1-10, plates 60 and 62 suitably include pass through ports 78 and 80 which are not in medium communication with the path defined by ports 64 and 66 of this plate. Ports 78 and 80 serve to pass medium from an immediately adjacent plate (above or below), to the next plate above or below.

Plate 62 of FIG. 12 employs corresponding structures to the plate of FIG. 11. However, in this particular embodiment, plate 62 is a mirror image of plate 60. Accordingly, when the plates are stacked together to construct a heat exchanger in a manner corresponding to that described previously in conjunction with FIGS. 1-10, the flow direction of

medium in any two immediately adjacent plates is 180° out of phase. For example, if the flow path for plate 60 is from port 64, through the micro-channel structures and out port 66, in plate 62 immediately therebelow (or thereabove), the flow path is from port 66′, through the micro-channel structures and out of port 64′. Since separate media are being passed through the two plates, heat transfer between the two takes place. The arrangement thereby provides true counter-current flow between the heat exchanging media. By varying the number of micro-channel plates, each heat exchanger can be easily sized to handle the specific heat capacity requirements of any given system.

Suitable dimensions of the plates are, with reference to FIG. 12, a plate thickness of 5.0 mm, a micro-channel width of 0.25 mm, a channel depth of 3.0 mm, and a 0.75 mm channel spacing. Overall plate width 82 is 300 mm, with medium flow area 84 being 220 mm. The distance 86 between the center of one finger 72 and the center of adjacent finger 74 is 20 mm. The overall length 88 of a given micro-channel area 76 is 125.5 mm, while the width 90 at the opening of a given finger region 72 or 74 is 8 mm typically.

While the first and second plates illustrated in this embodiment both employ corresponding micro-channels, alternative second plates can be employed which do not include micro-channels, for use with medium media that do not warrant the use of micro-channels, and only require a pass channel comprising a substantial area of the plate (as would be produced by removing the material to a depth of 3 mm in the illustrated embodiment throughout the areas of the micro-channels 76.)

The use of relatively long (greater than 125 mm in the illustrated embodiment) finger areas 72 and 74 with

relatively short (less than 20 mm in the illustrated embodiment) micro-channel members that the medium passes through, is advantageous in providing a low pressure drop between the inlet and outlet sides of the system.

Referring now to FIG. 13, a perspective top face view of another alternative embodiment rectangular micro-channel plate, FIG. 14, a cross sectional view taken along line 14—14 in FIG. 13 and FIG. 17, a magnified view of a portion of the plate of FIG. 14, an embodiment of a rectangular micro-channel plate according to the present invention is illustrated. Rectangular plate 100 is configured in a manner corresponding to that of the square plate configuration shown in FIGs. 11 and 12, with pass through ports 78′ and 80′ and inlet and outlet ports 64′ and 66′. Relatively long finger areas 130 with relatively short micro-channel members 132 that a medium passes through, are advantageously provided, to enable a low pressure drop between the inlet and outlet sides of the system. A sealing O-ring groove is provided for embodiments that are adapted for being disassembled.

Suitable dimensions of rectangular plate 100 with reference to FIG. 14 are, plate thickness 102 of 6.4 mm (0.25 inch), micro-channel width 104 of 0.5 mm (0.02 inch) and micro-channel fin thickness 106 of 0.38 mm (0.015 inch).

While rectangular plate 100 employs micro-channels, the correspondingly stacked mirror image plate may or may not have micro-channels, depending upon the specific characteristics of the media involved. Media that do not warrant the use of micro-channels will employ a pass channel similar to that discussed in the other plate embodiments.

Rectangular configured plates are desirably used in larger capacity heat removal applications as more heat transfer capacity per heat exchanger volume can be accomplished compared to heat exchangers comprised of circular or square configuration micro-channel plates. Rectangular configured plates also reduce the overall length of the heat exchanger plate stack for a given heat removal load. A rectangular plate heat exchanger according to the invention is assembled of rectangular plates and corresponding mirror image plates that are alternately stacked to give efficient counter current flow, whereas in a circular plate heat exchanger, all plates can be substantially similar and vary in the heat exchanger stack only by their orientation.

Referring now to FIGs. 15 and 16, a perspective top face view of the preferred alternative embodiment rectangular micro-channel plate and a cross sectional view thereof along line 15-15, the preferred rectangular plate 110 has corresponding features to rectangular plate 100 as shown in FIGs. 13, 14 and 17, and may also be fabricated in a mirror image arrangement that is alternately stacked to give efficient counter current flow through an assembled heat exchanger. Plural micro-channel regions 132′ and finger regions 130′ are provided, as well as inlet and outlet ports 64′′, 66′′, 78′′ and 80′′. A sealing O-ring groove is also provided as necessary.

Suitable dimensions of the preferred embodiment rectangular configured plate 110 are, plate thickness 112 of 6.4 mm (0.25 inch), fin width 114 of 0.5 mm (0.020 inch), micro-channel width 116 of 0.38 mm (0.015 inch), and micro-channel depth 118 of 3.8 mm (0.15 inch). The overall plate width 122 is 14 cm (5.50 inch), and the overall plate length 120 is 21.8 cm (8.60 inch). The distance 124 between the center of

one finger and the center of an adjacent finger is 2.5 cm (0.9875 in). The overall length 126 of a given micro-channel is 1.8 cm (0.70 inch), while the width 128 at the opening of a given finger region is typically 9.5 mm (0.375 inch).

While the rectangular plate 110 illustrated in this preferred embodiment employs micro-channels, the correspondingly stacked mirror image plate may or may not include micro-channels.

Accordingly, large capacity micro-channel heat exchangers are provided in accordance with the invention, for use in commercial HVAC (heating ventilation air conditioning), residential scale HVAC and industrial process cooling and heating. Using a high efficiency micro-channel heat exchanger according to the invention can improve the efficiency of HVAC/R (heating ventilation air conditioning/refrigeration) systems and process cooling systems, resulting in reduced energy consumption. Additionally, the high rate of heat transfer afforded by the invention and the high heat transfer surface area to volume ratio results in considerably physically smaller heat exchangers relative to conventional heat exchangers.

Since heat transfer in laminar flow micro-channels is a function of the Nusselt number, fluid velocities have little impact on heat transfer. Thus, the micro-channel heat exchanger of the present invention is capable of efficiently operating with low volumetric flow rates which in turn reduce pressure losses within the heat exchanger, thereby increasing overall heat exchanger efficiency.

While the illustrated embodiment employs metal (for example, aluminum) as the material from which an individual plate is fabricated (by milling, for example), other materials may be employed, even

materials having lower heat conductive properties than metals. The general formula for heat transfer in a plate having 2 media on opposite sides is:

$$U = \frac{1}{\frac{1}{h_1} + \frac{1}{\frac{k}{l}} + \frac{1}{h_2}}$$

where "h_1" is the heat transfer into the solid plate material from the first medium, "h_2" is the heat transfer into the solid from the second medium, "k" is the conductivity of the solid and "l" is the dimension. Since a given plate has a very small value of "l" (given the micro-channel construction and relatively small dimensions between media), the value of k/l is large, and 1/(k/l) is small (i.e. goes to zero) and therefore the conductivity of the material is relatively unimportant. "k" can be small, since "l" is small. Therefore, a micro-channel plate can be manufactured of a polymer or polymer composite, which makes manufacturing of an individual component relatively inexpensive in contrast with the expense of making a machined metal component plate. A hybrid micro-channel plate comprises micro-channel portions formed of metal machined to define the micro-channels, wherein the rest of the plate is formed of a polymer. The metal micro-channel portions are suitably attached to the polymer. Still further, the plates can be manufactured entirely from a composite of polymers and other materials (e.g. carbide fibers, metal fibers, graphite fibers, or metal spheres) to enable injection molding of the plates, while still incorporating some features of metal conductive properties. A suitable polymer is, for example, RTP 3499X83072 liquid crystal polymer, from RTP Company, 580 East Front Street,

Winona, Minnesota 55987 US. Less brittle polymers than this particular example are also desirable.

A micro-channel heat exchanger constructed of polymer composite (resin and graphite fiber or other composite) has several advantages over current conventional type polymer heat exchangers being used in caustic and corrosive fluid processing applications. A polymer composite micro-channel heat exchanger is smaller than the common shell and tube formats. The polymer composite micro-channel heat exchanger is also considerably less costly to produce than the shell and tube heat exchangers made of synthetic resinous fluorine-containing polymers (e.g. Teflon) or other exotic inert materials plate heat exchangers used in corrosive environments. Finally, the polymer composite micro-channel heat exchanger has comparable performance to metal micro-channel heat exchanger models and can incorporate structural ribs to add strength.

In accordance with the invention, a large capacity heat exchanger (for example where the amount of energy transferred exceeds 1,000 Btu/hr) is suitably constructed by using plural plates in alternating arrangement. The medium can be gas, liquid or two-phase flow. Working pressures commonly used are in the range of 425 psig while working temperatures commonly employed are in the -60°F to 390°F range. Heat transfer coefficients for single phase liquids as high as 15,000 W/m^2-K have been achieved and heat transfer coefficients for two phase flow as high as 35,000 W/m^2-K have been achieved although these figures are not meant to represent upper boundaries or limitations of the present invention. Because of the flexible design feature of being able to incorporate additional plates into the heat exchanger, the heat removal capacity for this style of heat exchanger is

unlimited. For efficiency reasons, as the heat capacity requirements increase, square and rectangular plate configurations are better suited to handle the larger loads than are circular plate configurations.

The plates are suitably fabricated in circular or rectangular shape, and while bolted together in the preferred embodiment, the plates may also be permanently secured together by welding, brazing, use of adhesives or equivalent mechanical methods, depending upon the application and their need for future disassembly. Alternate embodiments that are not intended to be disassembled, do not incorporate O-ring grooves and O-rings for sealing against commingling of the mediums, but rather have the mating areas around the apertures and the plate circumference directly sealed during the fabrication process. This type of embodiment enjoys the advantages of reduced size (since compressible O-rings are not required), as well as the freedom from possible O-ring failures.

Accordingly, improved heat exchangers have been shown and described, with various alternative configurations. For example, an alternate embodiment consists of a second plate having larger channels or even a single channel rather than a plurality of micro channels, placed between micro-channel plates. Alternate stacked plates in the assembled heat exchanger may be substantially identical to each other or may be substantially mirror images of each other. The flow directions between the media may be other than perpendicular. Counter current flow although preferred may be replaced by parallel flow. The plates may or may not incorporate O-ring grooves and O-rings. The heat exchanger may or may not be able to be disassembled, and may or may not incorporated a shell type enclosure around the stack of heat exchanger

plates. The fluid media may be liquid, or gas, or combinations thereof, for example. The first and second media need not be the same.

Thus, in accordance with the invention, advantages provided include improved commercial plate heat exchangers that are smaller in size with respect to conventional commercial heat exchangers, disposable plate heat exchangers that are easily and inexpensively produced such that replacement is more economical than cleaning, repair or refurbishment, and plate heat exchangers having a heat removal capacity that can be altered in the field by addition or removal of heat exchanger plates, thereby eliminating the need for multiple designs based on differing heat capacity ranges. Other advantages include providing heat exchangers that do not require welding for assembly, thus facilitating ease of field disassembly for repair, modification, relocation or cleaning. The heat exchangers can be cheaply and easily shipped in small units for assembly in situ by the customer. The construction of the individual plates provides an improved heat exchanger that achieves an efficient transfer of energy at a minimum pressure loss, allowing as large a fluid capacity as desired to efficiently flow through micro-channels at a desired Reynolds Number that provides maximum heat transfer at reasonable pressure drops. Fluid velocities through the heat exchanger can be reduced as well as fluid pressure losses, by adding micro-channel plates as desired to create additional parallel flow paths without significantly reducing heat transfer from an increase in boundary layer effects.

The micro-channel heat exchanger plates are suitably fabricated of metals, polymers, or polymer composite materials. A particular composite plate

employs liquid crystal polymer composite material with graphite fibers aligned so as to enhance thermal conductivity between the heat transfer fluids.

While plural embodiments of the present invention have been shown and described, it will be apparent to those skilled in the art that many changes and modifications may be made without departing from the invention in its broader aspects. The appended claims are therefore intended to cover all such changes and modifications as fall within the true spirit and scope of the invention.

Claims

We claim:

1. A plate having a top side and a bottom side for use in a heat exchanger device, comprising:
a plurality of micro-channels on the top side, wherein each micro-channels is characterized as having a height of from about 2 to about 12 mm, a channel width of from about 0.1 to about 1.0 mm, a separation wall between micro-channels of from about 0.1 to about 1.0 mm and a channel length of from about 1 cm to about 5 cm.

2. A plate according to claim 1 wherein said plate is predominantly circular in shape.

3. A plate according to claim 1 wherein said plate is predominantly quadrilateral in shape.

4. A plate according to claim 1, wherein said plate has an inlet opening and an outlet opening each communicating with opposite ends of a series of said plurality of micro-channels.

5. A plate according to claim 1, wherein said plate is manufactured of a metal.

6. A plate according to claim 1, wherein said plate is manufactured of a polymer.

7. A plate according to claim 1, wherein said plate is manufactured of a polymer/graphite composite.

8. A plate according to claim 1, wherein said plate is manufactured of a polymer/metal composite.

9. An apparatus for transferring heat between a first and second medium, comprising:

a first plate having plural micro-channels formed on a surface thereof, said micro-channels defining a path of travel for the first medium;

a second plate, defining a path of travel for the second medium,

wherein said first and second plates are stacked adjacent each other to enable transfer of heat between the first and second media.

10. An apparatus according to claim 9 wherein at least one of said first plate or said second plate comprises:

a plurality of micro-channels on a top side, wherein each micro-channels is characterized as having a height of from about 2 to about 12 mm, a channel width of from about 0.1 to about 1.0 mm, a separation wall between micro-channels of from about 0.1 to about 1.0 mm and a channel length of from about 1 cm to about 5 cm.

11. An apparatus for transferring heat according to claim 9, comprising plural ones of said first plates and plural ones of said second plates, said plural first and second plates positioned adjacent one another in alternating fashion.

12. An apparatus for transferring heat according to claim 11 wherein ones of said first plates are of circular configuration and are rotated relative to ones of said second plates.

13. An apparatus for transferring heat according to claim 11 wherein ones of said first plates direct said path of travel for first medium parallel relative to said path of travel of second medium through ones of said second plates.

14. An apparatus for transferring heat according to claim 11 wherein ones of said first plates direct said path of travel for first medium countercurrent relative to said path of travel of second medium through ones of said second plates.

15. An apparatus for transferring heat according to claim 11, wherein said first plate has a first medium inlet aperture and a first medium outlet aperture defined therein, wherein said micro-channels are formed between said apertures such that a flow path for the first medium is defined from the inlet aperture through the plural micro-channels and through the outlet aperture.

16. An apparatus for transferring heat according to claim 15, wherein said second plate has a second medium inlet aperture and a second medium outlet aperture defined therein, wherein said path of travel is formed between said apertures such that a flow path for the second medium is defined from the inlet aperture and through the outlet aperture.

17. An apparatus for transferring heat according to claim 16, wherein said first plate has two second medium pass through apertures defined therein, to enable the second medium to flow through said first plate without passing through said micro-channels thereon.

18. An apparatus for transferring heat according to claim 16, wherein said second plate has two second medium pass through apertures defined therein, to enable the first medium to flow through said second plate without passing through said path of travel.

19. An apparatus for transferring heat according to claim 9, wherein said micro-channels of said first plate have a height of approximately 3 mm per micro-channel, a micro-channel width of approximately 0.25 mm, adjacent micro-channels are separated by approximately 0.5 mm and the micro-channel length is approximately 15 mm.

20. An apparatus for transferring heat according to claim 9 wherein said second plate comprises plural micro-channels formed thereon for defining the flow path of said second medium.

21. An apparatus for transferring heat according to claim 20, wherein said first and second plates have a plurality of holes, that align upon stacking of said plates for receiving a fastening means therethrough to secure said plates together.

22. An apparatus for transferring heat according to claim 9 wherein the path of travel of said first and second media are counter current across a portion of said first plate and said second plate.

23. An apparatus for transferring heat according to claim 9 wherein said first plate and said second plate comprise substantially mirror images of each other.

24. An apparatus for transferring heat according to claim 9 wherein said first plate comprises a relatively long input finger channel defining an input flow path, and a relatively long output finger channel defining an output flow path, wherein plural relatively short micro-channels are defined therebetween, wherein the heat exchanger provides relatively low pressure drop between the input and output sides thereof.

25. An apparatus for transferring heat according to claim 24 further comprising:

a first end plate with a first medium opening and second medium opening defined therein; and

a second end plate with a first medium opening and second medium opening defined therein

wherein said first and second end plates are located at the distal ends of said heat exchanger, and wherein said first medium opening on said first end plate is an inlet opening and said second medium opening on said first end plate is an outlet opening, and said first medium opening on said second end plate is an outlet opening and said second medium opening on said second end plate is an inlet opening so as to facilitate counter current flow within the heat exchanger.

26. A heat exchanger comprising at least 2 plates containing multiple micro-channels therein, assembled for the purpose of exchanging heat between two fluids, one of said plates containing four or more holes that align with one another on respective plates when said plates are positioned adjacent each other for defining entrance and exit plenums;

wherein a first fluid flows from an entrance plenum through micro-channels in every other plate and

exits the heat exchanger through a second exit plenum, and a second fluid flows from another entrance plenum through micro-channels in the other every other plate and exits said heat exchanger through another second exit plenum.

27. A heat exchanger according to claim 26 wherein a flow path of said first and said second fluids are counter current across a portion of said plates.

28. A heat exchanger according to claim 26 wherein a first of said plates comprises substantially a mirror image of a second of said plates that is adjacent thereto.

29. A heat exchanger according to claim 26 wherein said plates comprise a relatively long input finger channel defining an input flow path, and a relatively long output finger channel defining an output flow path, wherein said micro-channels are plural relatively short micro-channels defined therebetween, wherein the heat exchanger provides relatively low pressure drop between the input and output sides thereof.

30. A heat exchanger comprising at least 2 plates containing multiple micro-channels, wherein said heat exchanger is capable of transferring at least 1,000 Btu/hour.

31. A heat exchanger according to claim 30 wherein flow paths of heat transfer media flowing through the plates of said heat exchanger are counter current across a portion of said plates.

32. A heat exchanger according to claim 30 wherein a first of said plates comprises substantially a mirror image of a second of said plates that is adjacent thereto.

33. A heat exchanger according to claim 30 wherein said plates comprise a relatively long input finger channel defining an input flow path, and a relatively long output finger channel defining an output flow path, wherein said micro-channels are plural relatively short micro-channels defined therebetween, wherein the heat exchanger provides relatively low pressure drop between the input and output sides thereof.

34. A heat exchanger comprising at least two plates, wherein a first said plate contains micro-channels, and a second said plate contains channels that are other than micro-channels.

35. A heat exchanger according to claim 34 wherein said plates comprise metal.

36. A heat exchanger according to claim 34 wherein said plates comprise polymers.

37. A heat exchanger according to claim 34 wherein said plates comprise polymer composites.

38. A heat exchanger according to claim 34 wherein said plates comprise polymer/metal composites.

39. A heat exchanger according to claim 34 wherein said plates are formed by an injection molding process.

40. A heat exchanger according to claim 34 wherein flow path of first and second heat transfer fluids are counter current across a portion of said plates.

41. A heat exchanger according to claim 34 wherein said first plate comprises a relatively long input finger channel defining an input flow path, and a relatively long output finger channel defining an output flow path, wherein said micro-channels are plural relatively short micro-channels defined therebetween, wherein the heat exchanger provides relatively low pressure drop between the input and output sides thereof.

42. A heat exchanger according to claim 34 wherein said plates comprise polymer/graphite composites.

43. A heat exchanger according to claim 42 wherein said graphite comprises aligned graphite fibers.

44. A heat exchanger according to claim 26 wherein said plates are removably secured together between end plates, said end plates defining entry and exit positions for said fluids into the heat exchanger.

45. A heat exchanger according to claim 26 wherein said plates are bonded together between end plates, said end plates defining entry and exit positions for said fluids into the heat exchanger.

46. A heat exchanger according to claim 26 wherein ones of said micro-channels have a depth of approximately 3.0 mm.

47. A heat exchanger according to claim 26 wherein ones of said micro-channels have a width of approximately 0.25 mm.

48. A heat exchanger according to claim 26 wherein adjacent ones of said micro-channels have a spacing of approximately 0.75 mm between centers thereof.

49. A heat exchanger according to claim 26 wherein ones of said micro-channels have a channel length of less than approximately 20.0 mm.

50. A heat exchanger according to claim 26 wherein ones of said plates have a thickness of approximately 5.0 mm.

51. A heat exchanger according to claim 26 wherein said plates comprise metal.

52. A heat exchanger according to claim 26 wherein said plates comprise polymers.

53. A heat exchanger according to claim 26 wherein said plates comprise liquid crystal polymers.

54. A heat exchanger according to claim 26 wherein said plates comprise polymer composites.

55. A heat exchanger according to claim 26 wherein said plates comprise polymer/metal composites.

56. A heat exchanger according to claim 26 wherein said plates comprise polymer/graphite composites.

57. A heat exchanger according to claim 56 wherein said graphite comprises aligned graphite fibers.

58. A heat exchanger according to claim 26 wherein said plates are formed by an injection molding process.

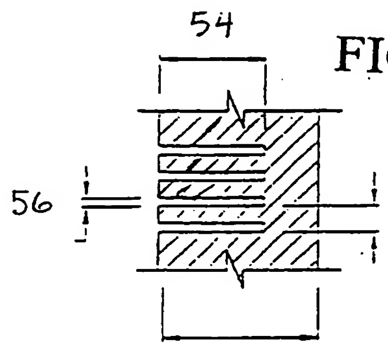


FIG. 1

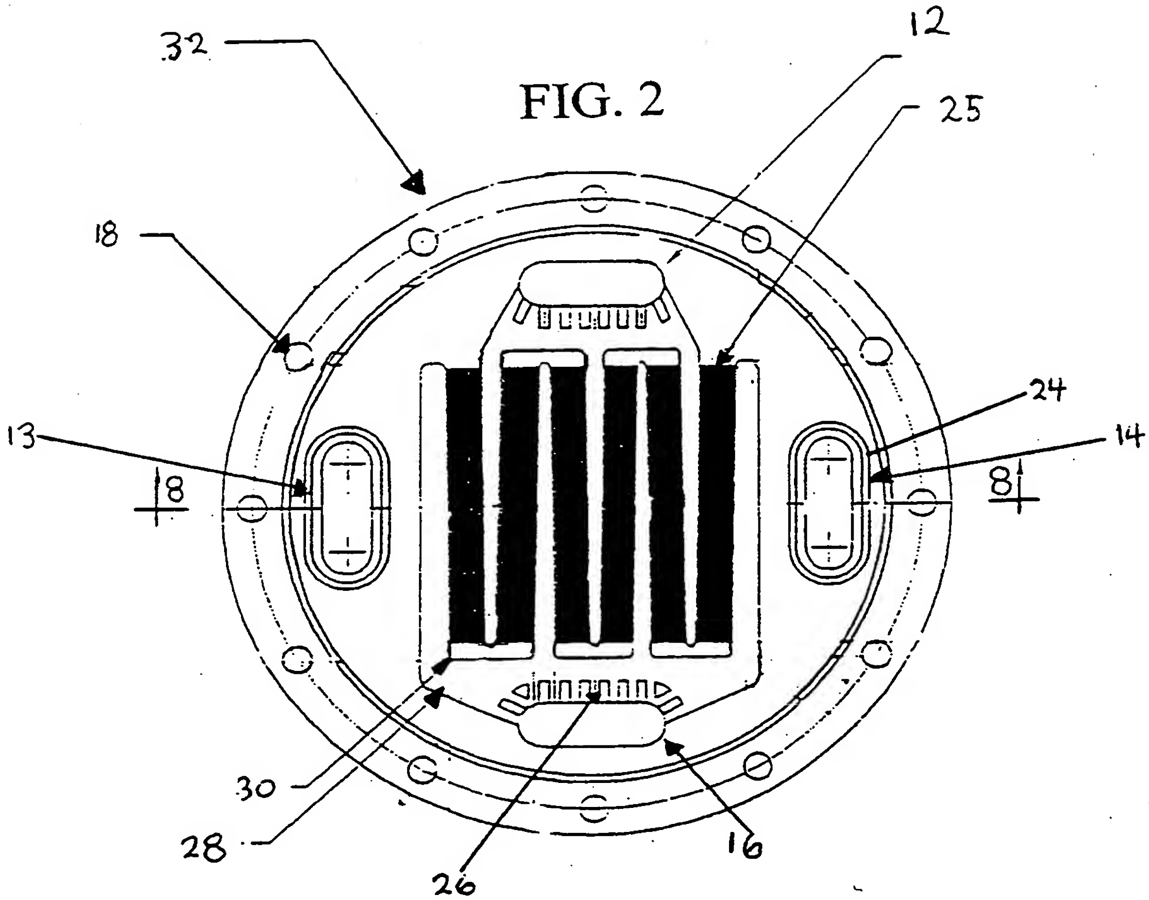


FIG. 2

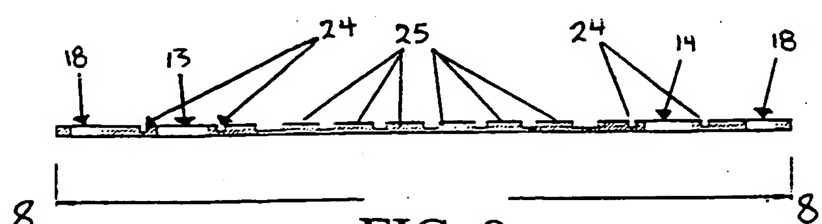
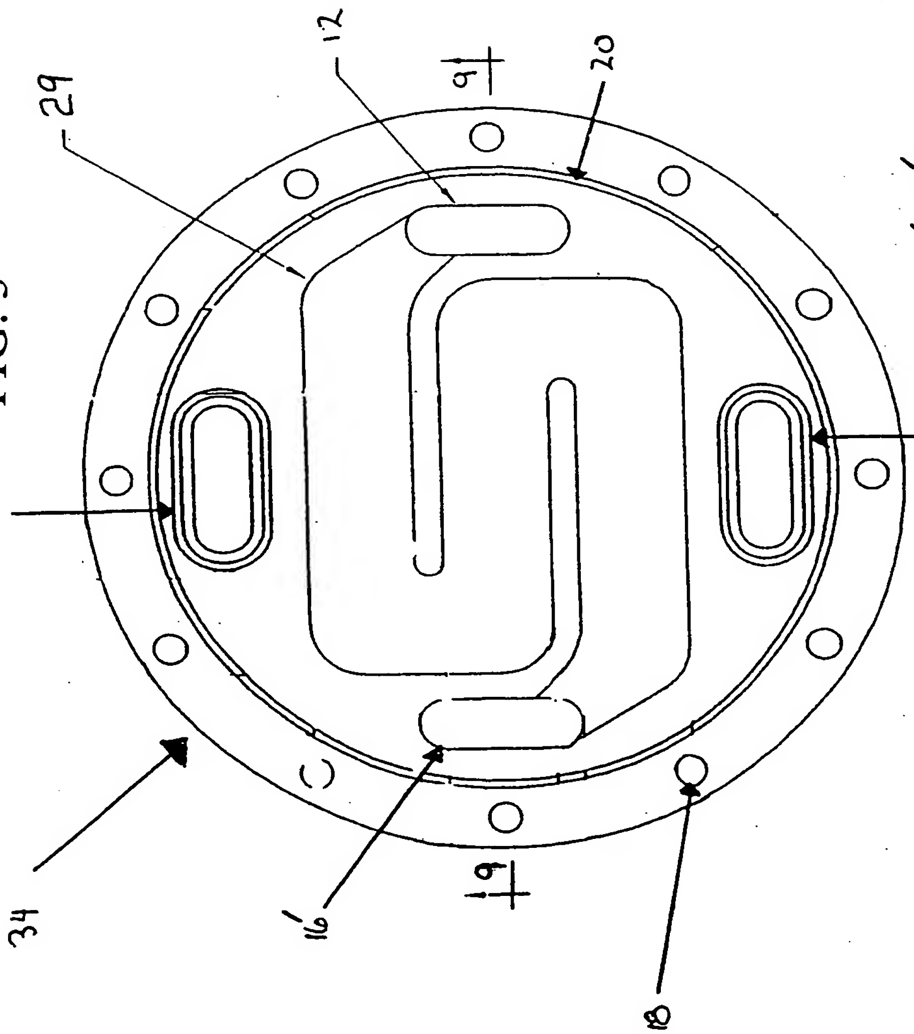


FIG. 8

FIG. 3



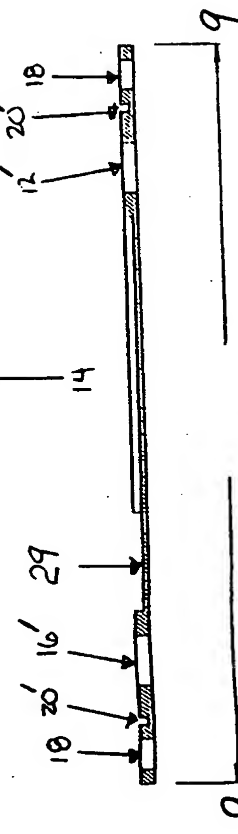


FIG. 9

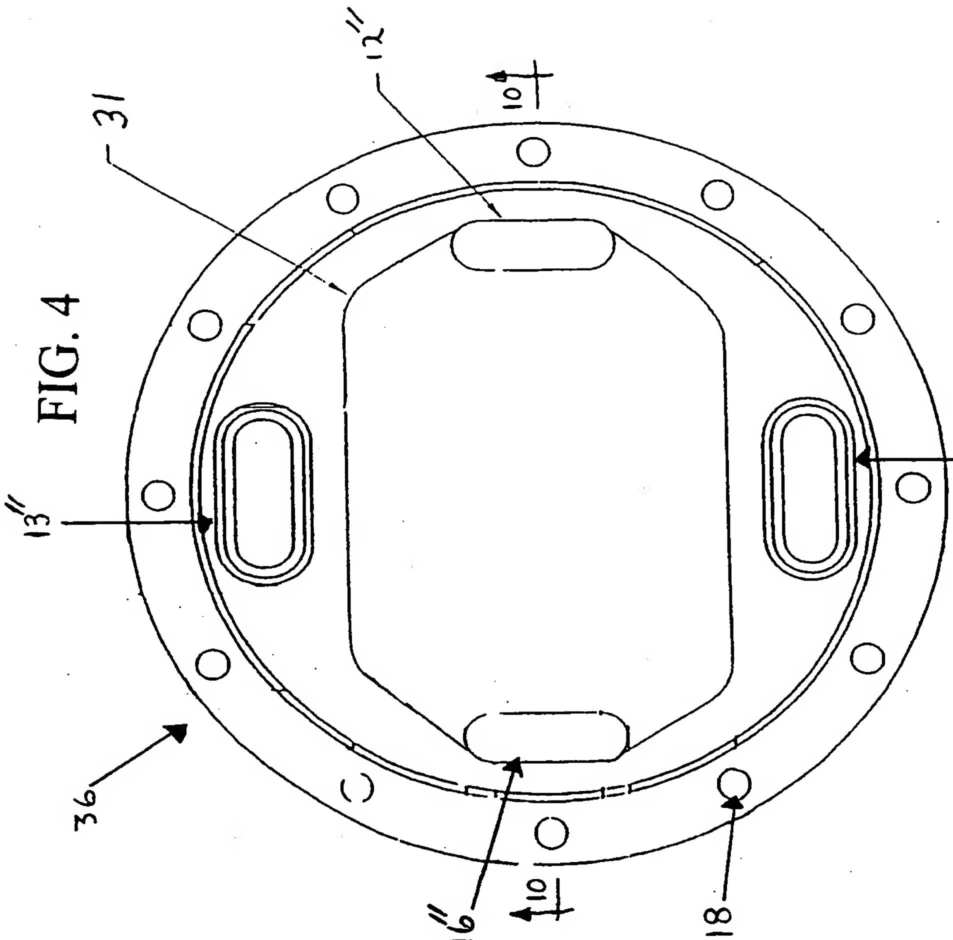


FIG. 4

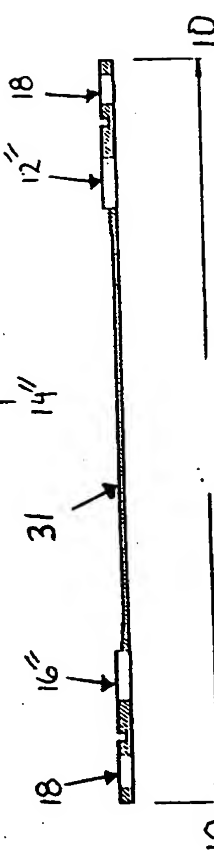


FIG. 10

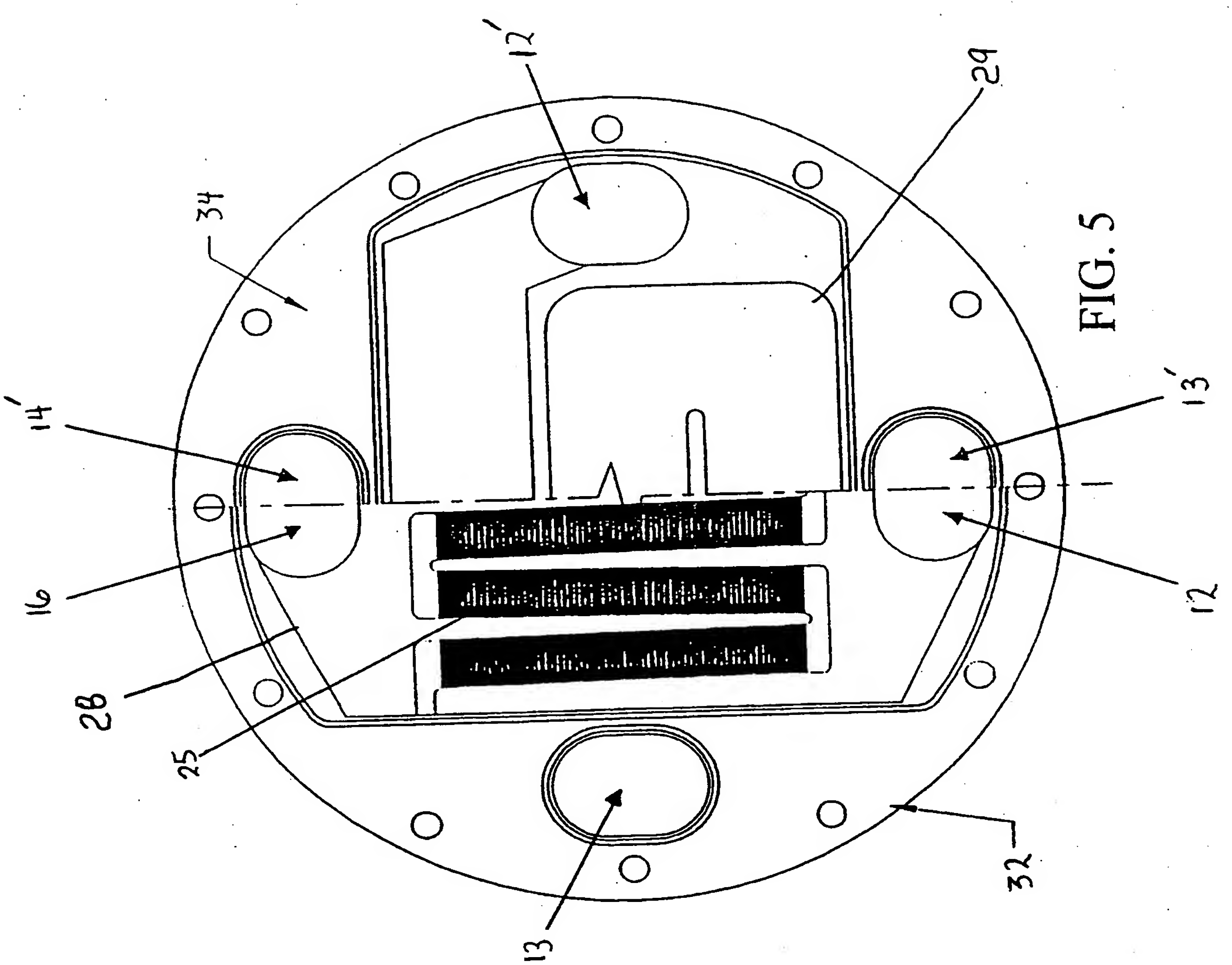


FIG. 5

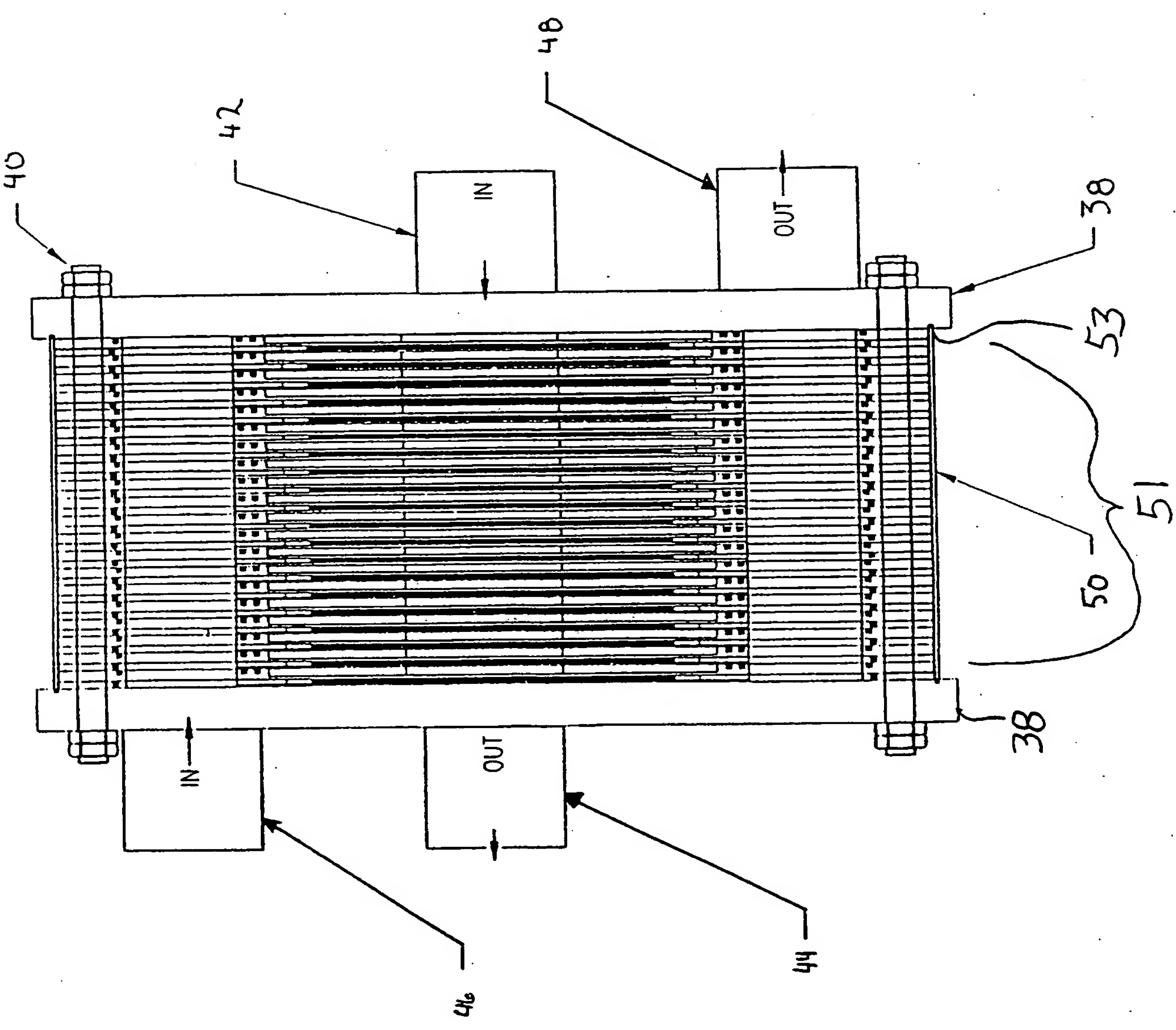
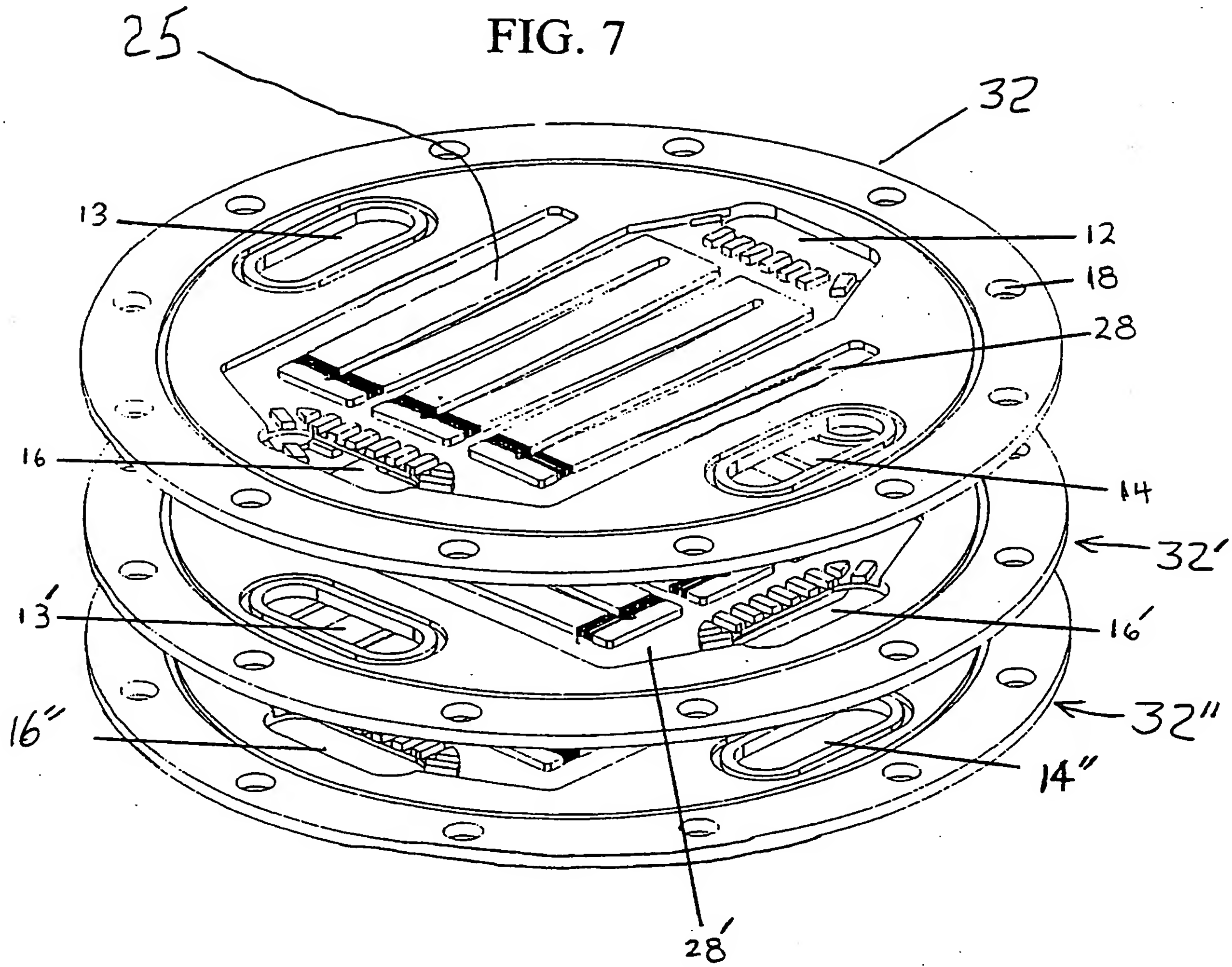


FIG. 6

FIG. 7



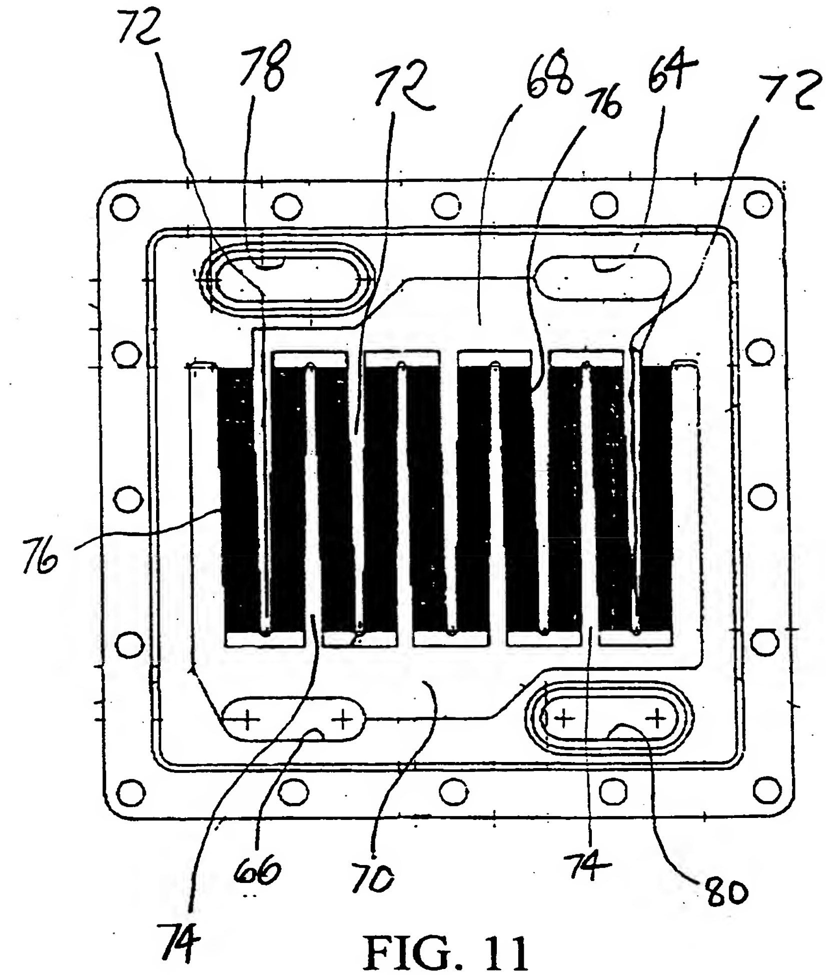


FIG. 11

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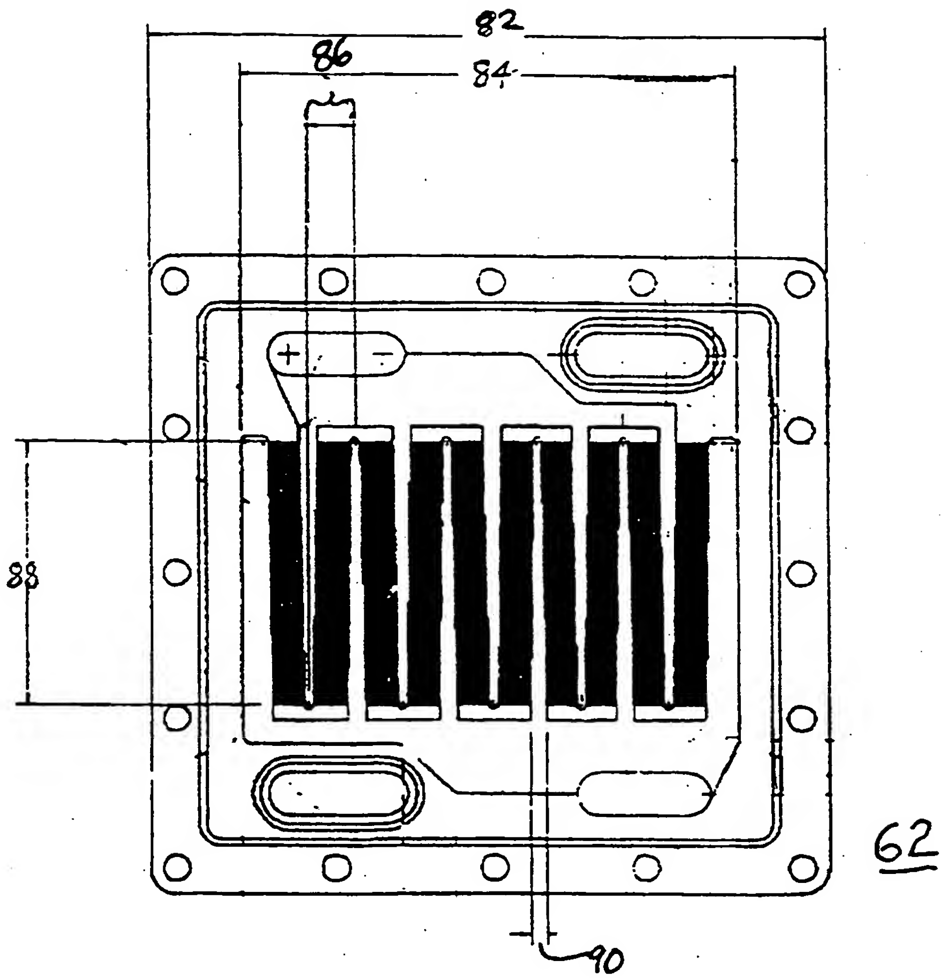

FIG. 12

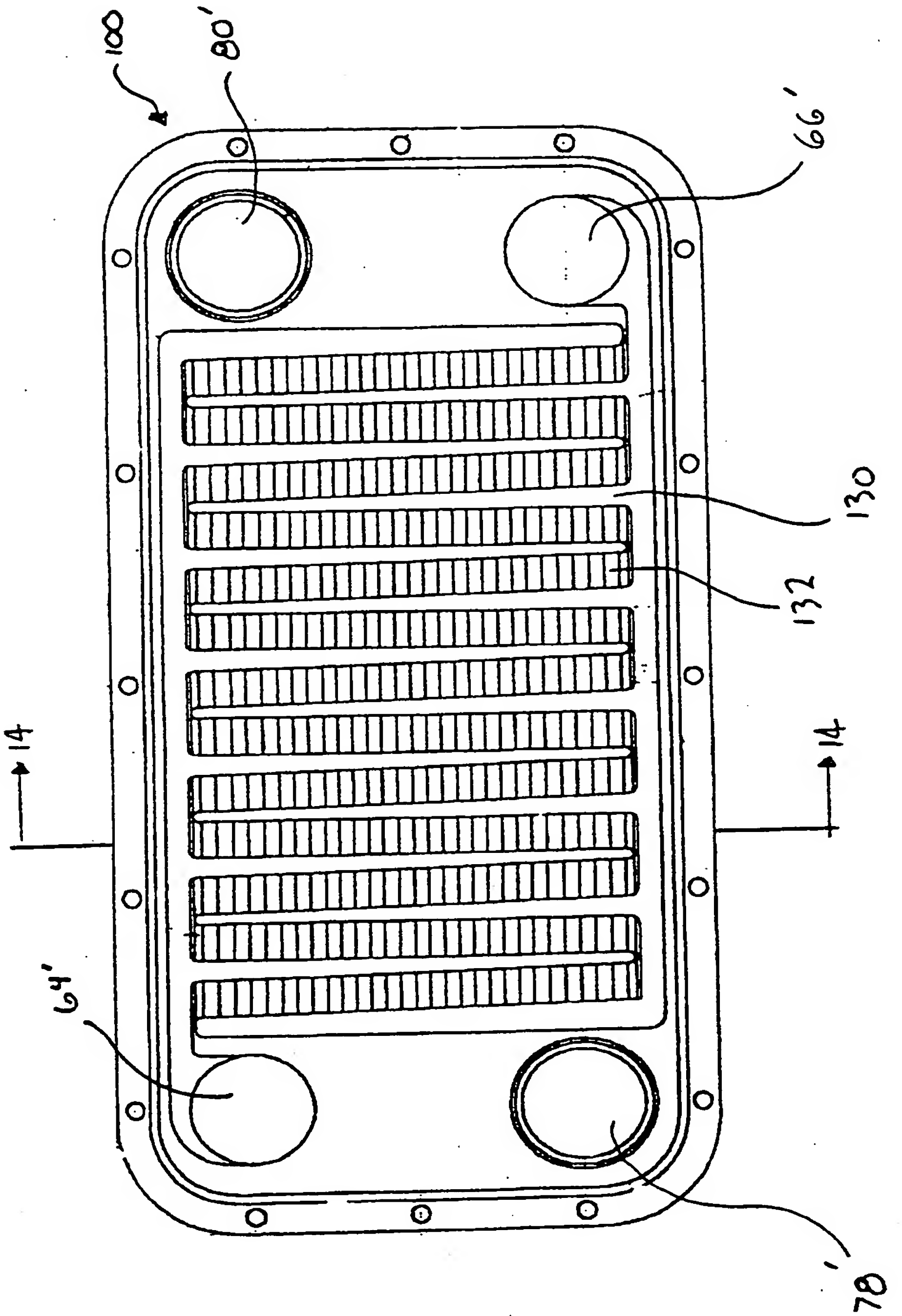

FIG. 13

FIG. 17

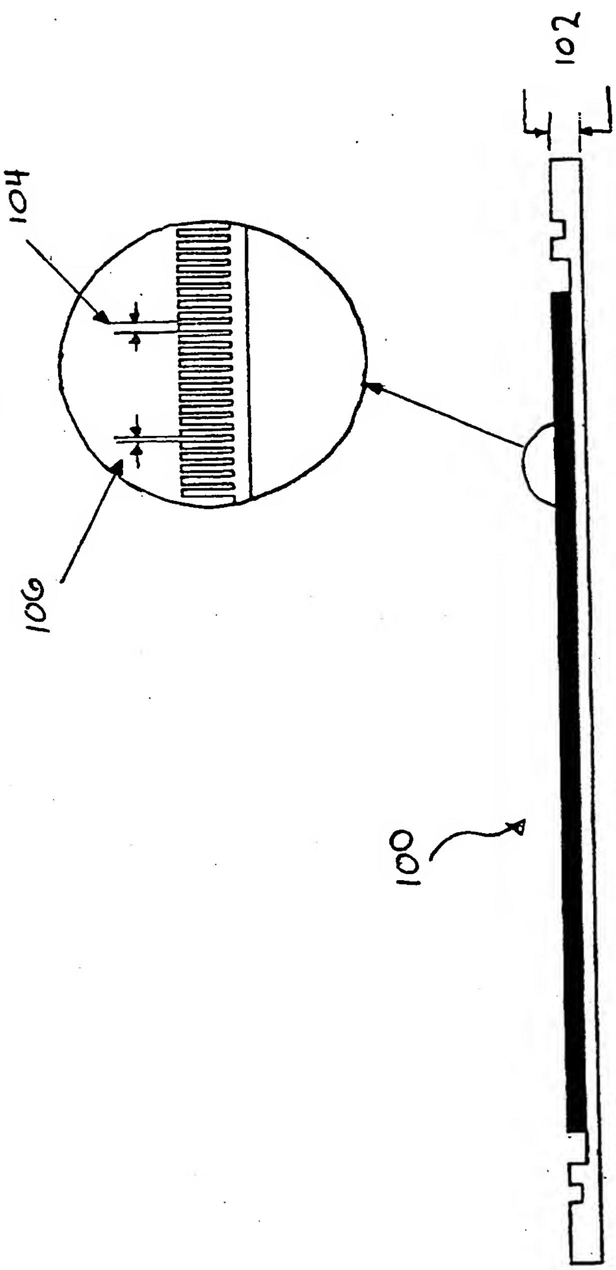

FIG. 14

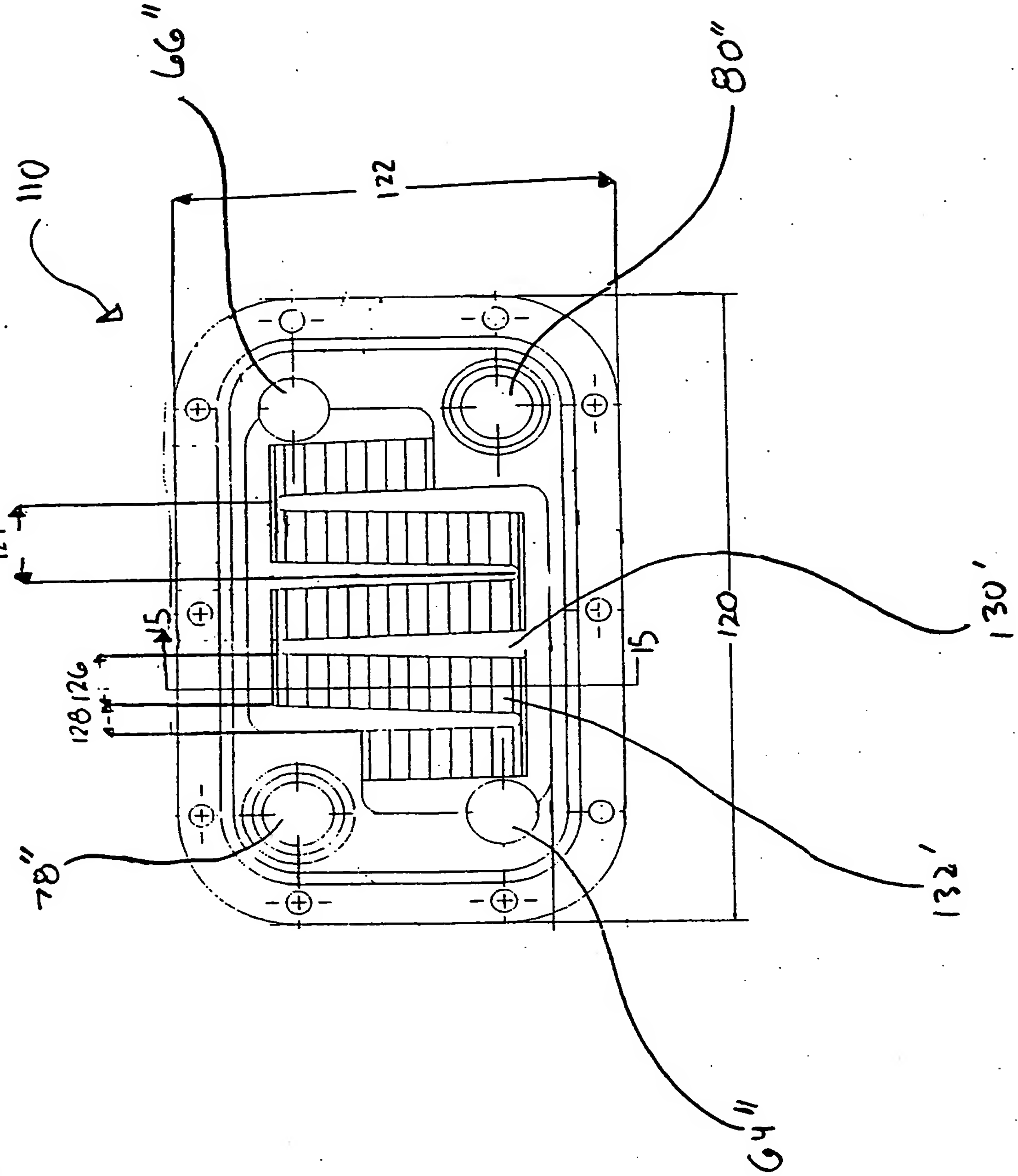

FIG. 15

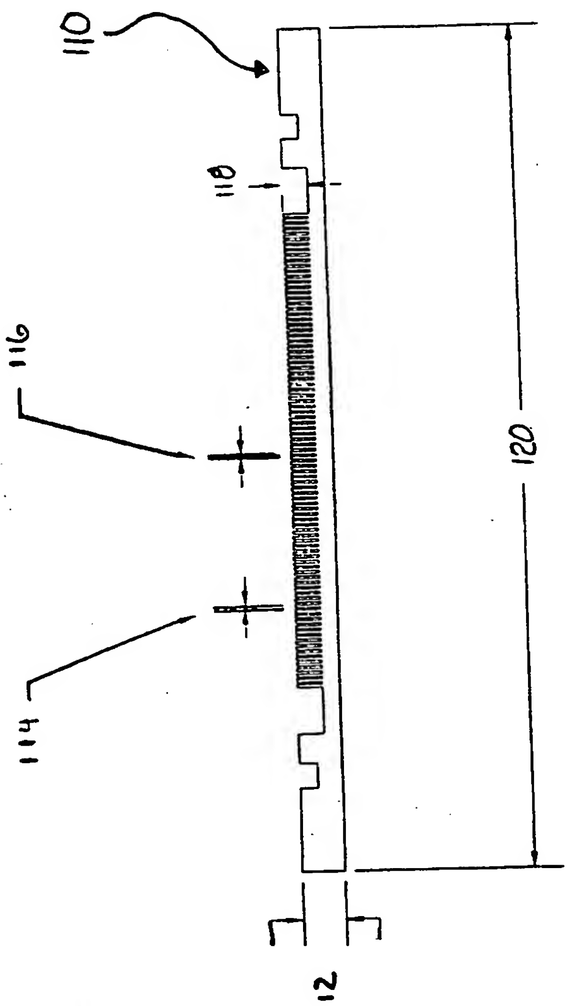

FIG. 16

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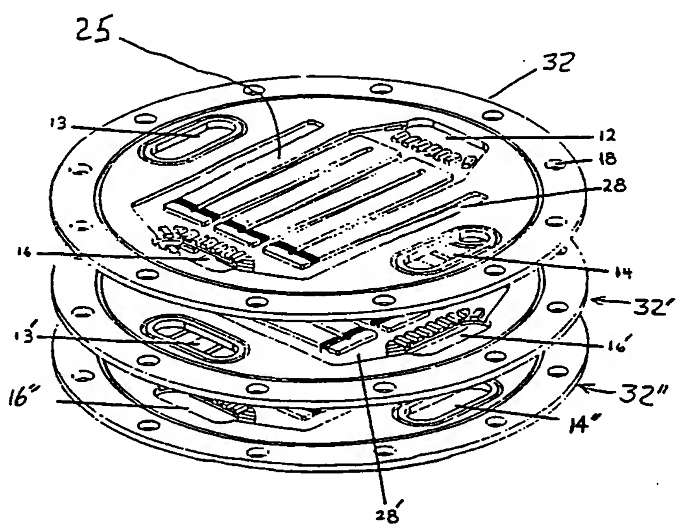
(57) Abstract

A plate (32) for a commercial size plate style heat exchanger utilizes micro-channels (25) in the flow paths (28) of the working media thereby greatly increasing the surface area to volume ratio and inducing laminar flow in the working media. This provides greater heat transfer capabilities and reduced pressure losses, resulting in an increased overall heat exchanger efficiency. The structure of the micro-channel plate heat exchanger is based on stacked micro-channel plates (32) that have been rotated 90 degrees with respect to each other.



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International application No.
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Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,072,784 A (STENLUND) 17 December 1991, see Figure 3.	1-58
Y	DT 3,844,040 A (HARADA) 27 July 1989, see all figures.	1-58

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